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ALERTNESS DEGRADATION AND CIRCADIAN DISRUPTION ON A U.S. COAST GUARD CUTTER UNDER PARAGON CREWING LIMITS

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16. Abstract (MAXIMUM 200 WORDS)

Crew alertness and the incidence of sleep/wake cycle disruptions were evaluated aboard DEPENDABLE, a WMEC, throughout 32 consecutive days underway. This study was conducted during the implementation of crew reductions prescribed by the Paragon project. Thirty male crew members volunteered to participate in the study. Wrist activity monitors (WAMs) were used to document sleep/wake cycles and electroencephalography (EEG) techniques were used to measure alertness. Thirty participants wore WAMs throughout the study period, while a subset of 14 volunteers participated in short duration EEG alertness tests every three to five days. Alertness tests were administered within three hours of wakefulness from daily sleep. Participants were allowed to follow their daily routine prior to reporting for the wakefulness tests. Unremarkable weather conditions and low operational tempo characterized this patrol. However, analysis of sleep/wake cycles and EEG alertness tests revealed a 59 percent incidence of sleep/wake cycle disruption associated with high failure rates in the EEG alertness tests. Twelve out of the 14 EEG participants failed to maintain wakefulness in 50 to100 percent of the tests. Participants working under non-rotating watch schedules (e.g., 0400-0800) exhibited consistent patterns of sleep and wake-up times with sleep duration rarely dipping below six hours. In contrast, participants exposed to frequent watch rotations showed disrupted sleep associated with the 0000-0400 and 0400-0800 watch schedule. Recommendations include the implementation of: a) a crew endurance education program to optimize the quality of crew rest; b) watch schedules that minimize sleep/wake cycle disruptions; c) the development of a system to reduce crew members' frequent rotation into the 0000-0400 or 0400-0800 watch schedules.

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EXECUTIVE SUMMARY

United States Coast Guard (USCG) missions often require rapid response, sustained operations, rapid transitions from daytime to nighttime duty hours, extended duty hours, and the implementation of rotating work schedules. The interaction of operational tempo, extreme weather conditions, sea states, crew experience, and work schedules can combine to reduce crew endurance, performance, and safety. Crew endurance depends on the ability to optimize crew rest and on the prevention of shiftwork maladaptation (or shift-lag). Shift-lag and lack of sufficient energy-restorative sleep induce fatigue (sleepiness, low energy, and lack of motivation), performance degradation during duty hours, and ultimately reduced safety.

Two experimental Coast Guard (CG) programs, namely Paragon (Atlantic Area 210-ft WMEC operations) and Exemplar (Pacific Area 378-ft WHEC operations), are exploring the potential use of reduced crew complements aboard cutters. One major concern is that crew reductions may exacerbate crew fatigue, and ultimately, compromise safety. Here, we present the results of the Paragon fatigue evaluation study conducted aboard the cutter DEPENDABLE (WMEC-210 ft) during a patrol from Portsmouth, Virginia, to Halifax, Nova Scotia, Canada. The central objective of this evaluation was to determine whether crew members experienced fatigue levels that may result in reduced safety.

Volunteers were solicited from crew stations affected by reductions prescribed in the Paragon program. All experimental procedures were reviewed and approved by a certified Institutional Research Review Board. A total of thirty crew members volunteered to participate in the crew fatigue evaluation. All volunteers were in good physical condition, with no history of chronic health problems. All information collected was kept confidential. Volunteers were informed that they could withdraw from the study at any time without consequences of any type.

METHODS

ALERTNESS TESTS

We used electroencephalography (EEG) techniques to measure individual alertness over a 32-day period while the cutter was on patrol. Fourteen of the original 30 volunteers participated in this alertness evaluation. Tests were conducted every three to five days (as permitted by duty cycles) within three hours of wake-up time from normal sleep. Participants were first instrumented with electrodes, connected to a portable EEG system, and asked to rest on a comfortable bed in a dark room. They were instructed to close their eyes and maintain wakefulness by mentally fighting the tendency to fall asleep.

In research and clinical sleep laboratories a similar test is used to determine the effects of sleep disorders on daytime sleepiness. Healthy individuals who sleep soundly and without disruption maintain wakefulness for at least 15 minutes. Individuals who experience consistent, but mild levels of sleep loss cannot maintain wakefulness beyond ten minutes. Research volunteers suffering from shiftwork maladaptation cannot maintain wakefulness beyond 8.2 minutes. Individuals with sleep disorders that induce severe daytime sleepiness usually fall asleep in less than ten and sometimes five minutes.

CREW ENDURANCE TESTS

TWENTY-FOUR HOUR SLEEP/WAKE CYCLES

Wrist worn activity monitors (the size of an oversize wristwatch) were used to document daily sleep/wake cycles. These devices were worn throughout the day, during work and sleep periods. Sleep/wake cycle data were collected from 25 of the original 30 volunteers (five discontinued participation) throughout 32 days. These data provide a daily history of activity and rest that permitted the assessment of sleep disruptions as a function of exposure to variable duty cycles and watch schedules.

RESULTS

Analysis of sleep/wake cycles and of EEG alertness tests revealed a high incidence of sleep/wake cycle disruption (59.0 percent) associated with high failure rates in the EEG alertness tests. Twelve out of the14 participants failed to maintain wakefulness on 50 to 100 percent of tests.

Participants working under non-rotating, stable watch schedules (e.g., permanent 0400-0800 watch) exhibited consistent patterns of sleep and wake-up times with sleep duration rarely below six hours. In contrast, participants exposed to frequently rotating schedules showed disrupted and fragmented sleep associated with the 0000-0400 and 0400-0800 watch schedules. These work schedules disrupted the organization of 24-hour or circadian sleep/wake cycles and resulted in sleep loss and fatigue (commonly referred to as shift-lag). Recovery from this condition takes a minimum of three to four days of a consistent work rest schedule including: sleep per night (preferably seven or more consolidated hours), wake-up times, daylight exposure, and work schedules. However, symptoms of fatigue may be experienced for several days after the realignment of sleep and work schedules.

CONCLUSIONS AND RECOMMENDATIONS

Unremarkable weather conditions and low operational tempo characterized this patrol. However, evidence of fatigue, as depicted by high failure scores in the alertness tests and frequent disruption of sleep/wake cycles, was frequently detected. Based on this evidence, crew endurance levels during this low tempo patrol were considered less than optimal.

Operational situations involving increased tempo and deteriorating weather conditions are certain to exacerbate fatigue symptoms. The following recommendations are offered to improve endurance levels:

1) implementation of crew endurance education programs to optimize underway crew rest and to prevent shift-lag;

2) implementation of watch schedules that minimize sleep/wake cycle disruptions; and

3) development of a system to optimize the number of watch qualified personnel underway and to reduce crew members' rotations into the 0000-0400 or 0400-0800 watch schedules.

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ACRONYMS

ANOVA	Analysis of Variance
CDI	Circadian Disruption Index
CG	Coast Guard
CGC	Coast Guard Cutter
EEG	Electroencephalogram
MSLT	Multiple Sleep Latency Test
MST	Multiple Sleep Test
MWT	Maintenance of Wakefulness Test
OTA	Office of Technological Assessment
RAM	Random Access Memory
USCG	United States Coast Guard
WAM	Wrist Activity Monitor
WHEC	High Endurance Cutter
WMEC	Medium Endurance Cutter
WRI	Wakefulness Reduction Index

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BACKGROUND

United States Coast Guard (USCG) mission objectives often require sustained operations, rapid transitions from daytime to nighttime duty hours, extended duty hours, and the implementation of rotating work schedules. In each mission, the interaction of operational tempo, extreme weather conditions, sea states, crew experience, and work schedules will impact crew endurance, performance, and safety. Personnel must endure harsh environments to accomplish search and rescue as well as law enforcement missions. Often, aviation and maritime assets are exposed to deteriorating weather conditions that have already compromised the safety of other vessels. During patrols, low tempo operations rapidly turn into heightened readiness and activity within minutes of receiving a rescue call. Similarly law enforcement and fisheries missions, involving boardings, require readiness, rapid response, and endurance.

High operational tempo requires boardings and helicopter deployments during normal duty hours (e.g., 0700-1700) and after duty hours. These evolutions can increase the daily work hours from approximately 9 to 10 hours/day to approximately 12 to 16 hours/day (Comperatore, Bloch, and Ferry, 1999).

High operational tempo is sustained according to operational requirements. For instance, if illegal fishing activities persist during nighttime hours for five consecutive days, a cutter assigned to patrol a specific region must maintain frequent activities over the same time period. This unpredictable element dictating operational tempo tests the endurance and readiness level of CG cutters and crew.

While a cutter's endurance is determined by how long it can support operations at sea without replenishing supplies, its crew members' endurance is a function of a complex multi-factorial. These factors include the internal state of crew members (e.g., emotional state, stress level), hours worked per day, quality and duration of rest periods (sleep), physical conditioning, diet, and stability level of the biological clock.

Crew endurance depends on the ability to optimize crew rest and the prevention of shiftwork maladaptation (or shift-lag). Crew members optimize crew rest as they take advantage of rest opportunities that allow consecutive hours of sleep. A minimum of six consecutive hours of sleep per day is required to prevent degradation of cognitive and physiological resources. Sleep periods of less than six hours have been associated with performance degradation, increasing sleep debt, and fatigue (Maas, 1998). Shiftwork maladaptation results from the inability to synchronize the human biological clock to rapidly rotating cycles of sleep and work. Adaptation to nighttime or daytime work requires the synchronization of physiological and cognitive resources under the regulation of the human circadian system (or biological clock). This system is a physiological mechanism composed of neural networks (e.g., hypothalamic deep brain nuclei) and hormonal outputs (e.g., pineal and pituitary glands) which regulate sleep (onset and quality), energy, and cognitive resources availability during active periods. Shiftwork maladaptation and poor quality sleep can result in persistent fatigue symptoms (e.g., sleepiness, low energy, lack of motivation, depression), and degrade performance. This condition increases operational risks and reduces safety. Other health effects such as increased incidence of cardiovascular disease, gastrointestinal disorders, and sleep disorders are common in populations exposed to shiftwork maladaptation for long periods of time (Office of Technological Assessment (OTA) report, 1991). Currently, the prevention of shiftwork maladaptation and sleep deprivation during USCG missions depends on existing crew management plans and watch schedules.

In FY98, two experimental USCG programs, namely Paragon (Atlantic Area 210-ft WMEC operations) and Exemplar (Pacific Area 378-ft WHEC operations) explored the potential use of reduced crew complements aboard medium and high endurance cutters. A primary concern is the impact of personnel reductions on safety during patrols. In this report, we present the results of the Paragon fatigue evaluation conducted aboard the Coast Guard Cutter (CGC) DEPENDABLE during a patrol from Portsmouth, Virginia, to Halifax, Nova Scotia, Canada. This study included the documentation of the incidence of degradation of alertness and of sleep/wake cycles. The central objectives of this evaluation were to determine whether crew members experienced fatigue levels that could result in compromised safety, and to provide recommendations that may control fatigue-related hazards.

METHODS

General Approach

This project was conducted in the months of August and September 1998, during USCG fishery patrol operations between Portsmouth, Virginia, and Halifax, Nova Scotia, Canada, aboard the USCGC DEPENDABLE (WMEC 626). The research plan consisted of the evaluation of crew endurance by documenting alertness level, daily sleep, and work/rest cycles throughout 32 days underway.

Initially, thirty crew members of the CGC DEPENDABLE volunteered to participate in the crew endurance evaluation. Twenty-five completed the study. Fourteen volunteers participated in alertness evaluations, which included the recording of brain activity during a maintenance of wakefulness test (MWT).

The research team boarded the DEPENDABLE at its homeport, and collected data throughout 32 days on patrol until arriving in Halifax. Within this time, the only interruptions to data collection were two- to three-day port calls to Boston, Massachusetts, and Portland, Maine.

Since participants' watch schedules, workload, and work schedules could not be controlled, it was not possible to use statistical designs, which required *a priori* groupings of participants. Descriptive statistics were used to describe individual changes in sleep and workload, both before and during the patrol. Analysis of variance and post-hoc comparison tests were conducted (see Appendix B for description of statistical approach and rationale) when statistically feasible.

Procedures

Procedures used during this investigation are similar to those used in studies completed under the Exemplar program aboard the WHEC MUNRO (Comperatore, Bloch, and Ferry, 1999). The critical dependent variables were alertness testing (EEG techniques) and activity/rest data collected with wrist activity monitors (WAMs).

In port familiarization phase and training

Prior to the underway evaluation, all participants were exposed to each phase of data collection in a sequence similar to the planned underway data collection procedures. Throughout five days in port, volunteers participated in the alertness and cognitive evaluations test sessions. Participants were originally asked to report for testing after a normal night of sleep (considered normal by each individual) and within three hours after awakening.

We used this familiarization phase to make sure that participants had an opportunity to experience all aspects of data collection procedures and to ask questions about the procedures prior to implementation during the underway phase of the study. Similarly, we used this period of time to adapt the research team to the ship's environment and to develop effective working relationships with the DEPENDABLE's crew.

On patrol data collection

Twenty-five participants wore wrist activity monitors (WAMs) used to document sleep and activity rhythms throughout 32 days on patrol. All WAMs were collected, downloaded, and reinitialized before each port call, and reissued upon resuming the patrol. Depending on work schedules resulting from patrol requirements, each volunteer (n = 14) participating in the alertness and cognitive evaluations underwent periodic (six to seven during the patrol) MWT sessions within three hours after awakening. The procedure consisted of a single test session that lasted approximately 90 minutes.

Participants

Crew members were solicited to participate in the study based on their occupational position. Initially, thirty crew members volunteered for the study. Three of the volunteers were not on board for the patrol because of health or family emergencies, and two volunteers asked to withdraw during the patrol. Of the twenty-five volunteers who completed the study, the average age was 27.9 and fifty-two percent were between 19-27 years of age. All volunteers were in good physical condition, with no history of abnormal brain activity, sleep disorders, or pre-existing health problems, and each maintained a current medical file with their ship's medical staff.

Volunteers were briefed on the right to withdraw from the evaluation without consequences, the confidentiality of the data, the experimental procedures, and the benefits and risks associated with participating in the study. After the research staff answered all questions and concerns, volunteers were asked to sign an informed consent form prior to their participation. All participants received identification numbers used on all measures (i.e., logbooks, questionnaires, performance data files, etc.) to identify their data throughout the study. Risks to participants were minimal, since the research plan did not prescribe the use of any invasive techniques or require significant changes in their daily duty routines. The experimental procedures used to evaluate crew endurance were reviewed and approved by a certified Institutional Research Review Board from Battelle Seattle Research Center, Inc. in Seattle, Washington.

Crew Endurance Evaluation

Wrist Activity Monitors (WAMs) were used to collect volunteers' sleep/activity data throughout 32 days underway. A WAM is a wrist-worn unit (the size of an oversize wristwatch) with dimensions of approximately 4.5 cm x 3.4 cm x 1.2 cm. It consists of a battery-powered microprocessor with nonvolatile RAM, containing a piezoelectric motion sensor and a real-time clock. The unit can detect accelerations associated with physical activity from 0.5 to 3.2 Gz and compares each signal against a voltage threshold of detection.

WAMS were used to document daily sleep/wake cycles. Volunteers wore WAMS throughout the day, during work, leisure, and sleep periods. Activity data provided a history of sleep and wakefulness that could be used to determine the time of sleep onset, the number of awakenings throughout the sleep period, wake-up times, and sleep duration. The analysis of sleep/wake profiles yields specific information on:

1) Daily changes in sleep onset and wake-up times,
2) Incidence of disrupted sleep patterns, and
3) Percent of sleep periods below six hours in duration.

These observations are of vital importance because research on shiftwork, travel across time zones, and sleep disorders consistently associates fatigue and adverse health effects with frequent loss of sleep, poor sleep quality, and day to day changes in wake-up times (more than two hours per day) (Mass, 1998; OTA report, 1991; Scott and Ladau, 1990).

Alertness Evaluation

This evaluation consisted of the documentation of personnel's ability to maintain wakefulness at times of the day when cognitive and physical energy should be available at peak levels. This period of time comprises the three hours following awakening from normal nocturnal sleep in personnel whose biological clocks are set to provide energy and cognitive resources during daylight hours. Personnel aboard the DEPENDABLE, as well as in all other high and medium endurance CG cutters, are considered daytime workers who must endure working night watch schedules from time to time. Their biological timing is not modified to optimize work during nighttime duty hours.

In clinical and experimental settings, sleep and wakefulness tests are used regularly to determine whether patients or test volunteers experience daytime sleepiness severe enough to compromise alertness and the ability to conduct activities that may affect individual or public safety (e.g., drive vehicles, decision making, etc.). These tests involve monitoring brain activity while patients attempt to maintain wakefulness (Maintenance of Wakefulness Test or MWT) or to fall

asleep (Multiple Sleep Latency Test or MSLT). During these tests, noticeable changes in brain wave frequencies indicate the exact moment of sleep onset (Campbell and Dawson, 1997; Pollak, 1997; Rechtschaffen and Kales, 1968). Sleep latency is scored by measuring the number of minutes that lapse from the beginning of the test (lights off in the test room) to the time of sleep onset.

Healthy individuals who sleep soundly seven or more hours per night can be expected to maintain wakefulness in MWTs for at least 15 minutes. Campbell and Dawson (1997) recently showed that alert and healthy participants, adapted to nighttime duty hours, exhibited sleep latencies exceeding 15 minutes in MWTs. In contrast, participants working nights but not physiologically adapted to nighttime work hours, consistently exhibited sleep latencies below 15 minutes. Campbell and Dawson (1997) described these MWT latencies, and in particular those below 8.2 minutes, as indicative of reduced alertness.

In clinical settings, patients with sleep disorders that induce moderate daytime sleepiness usually fall asleep in less than 10 minutes, while patients experiencing severe daytime sleepiness fall asleep within five minutes (Carskadon, Dement, Mitler, Roth, Westbrook, and Keenan, 1986; Pollak, 1997). The latter may be a cause for train conductors, truck drivers, or pilots to be suspended from transportation duties until the condition is corrected.

The procedures used in the wakefulness evaluations aboard the DEPENDABLE borrowed heavily from the clinical and experimental procedures used in the MWTs. The testing procedures used during the MWT are similar to those used by Campbell and Dawson (1997), while the scoring routines included information from Carskadon et al (1986), Campbell and Dawson (1997), and Pollak (1997). In this study, MWT latencies were categorized as to whether they were greater or less than 10 minutes, 8.2 minutes, and five minutes. The 8.2-minute threshold was used to detect severe alertness degradation above the pathological threshold of five minutes, but equal with the alertness degradation lower bound (8.2 min) reported by Campbell and Dawson (1997).

Wakefulness test participants were asked to report to the testing environments (either a stateroom

or the ship's gyrocompass room) within three hours of wake-up time every three to four days. This experimental constraint usually required volunteers to leave their departments during duty hours. Upon arrival to the test site, participants were first instrumented with electrodes, then connected to a portable electroencephalography system (EEG), and asked to rest on a comfortable bed in a dark room (temperature maintained between 65 - 75°F). Brain wave activity was monitored continuously to detect the transition from wakefulness to sleep using clinical methodology employed routinely in sleep laboratories (Rechtschaffen and Kales, 1968). Initially, participants were instructed to close their eyes and to allow themselves to fall asleep. They were allowed to rest under these conditions for 15 minutes, but they were awakened in two minutes if brain wave frequencies indicated the onset of sleep. Following this initial period of rest, participants were asked to remain awake and to speak to the research staff for five consecutive minutes under lights on. These procedures helped to equalize participants' internal state and to control for varying emotional states associated with each volunteer's activity prior to the test. At the end of this break period, the lights were turned off again; participants were asked to lie down and to relax with eyes closed, but to try to remain awake. Brain wave activity was continuously monitored and used to determine the total time that each participant could maintain wakefulness during a 15-minute session.

RESULTS

Alertness Evaluation

<u>Wakefulness maintenance tests</u>

Initially, the number of MWT latencies above and below ten minutes was calculated to determine the incidence of latencies identified as below normal in clinical settings. Figure 1 shows the percentage of total latencies (n = 87) above and below ten minutes.

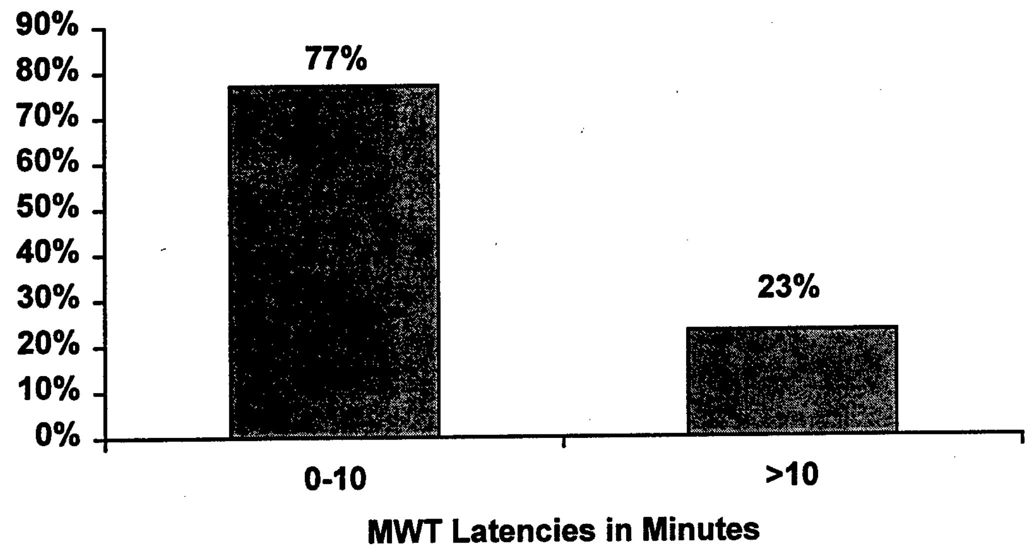

Figure 1. Percentage of MWT latencies above and below ten minutes. A total of 87 tests were administered throughout the patrol. Sixty-seven observations were below ten minutes. Latencies below ten minutes are considered clinically "below normal".

Considering that Campbell and Dawson (1997) reported alertness degradation with MWT scores below 15 minutes, the 77 percent of MWT latencies (a total of 67 scores) below ten minutes (shown in Figure 1) indicates a high incidence of alertness degradation among the test group. When the 67 latencies below ten minutes were further subdivided into categories of zero to five and five to ten minutes, the greater majority of latencies (54 of 67) were below the clinically pathological threshold of five minutes (Figure 2). In clinical settings, this level of alertness degradation suggests the influence of a sleep disorder that severely impairs performance and safety. It is of great concern that our participants, who had no sleep disorders, showed a similarly degraded level of alertness.

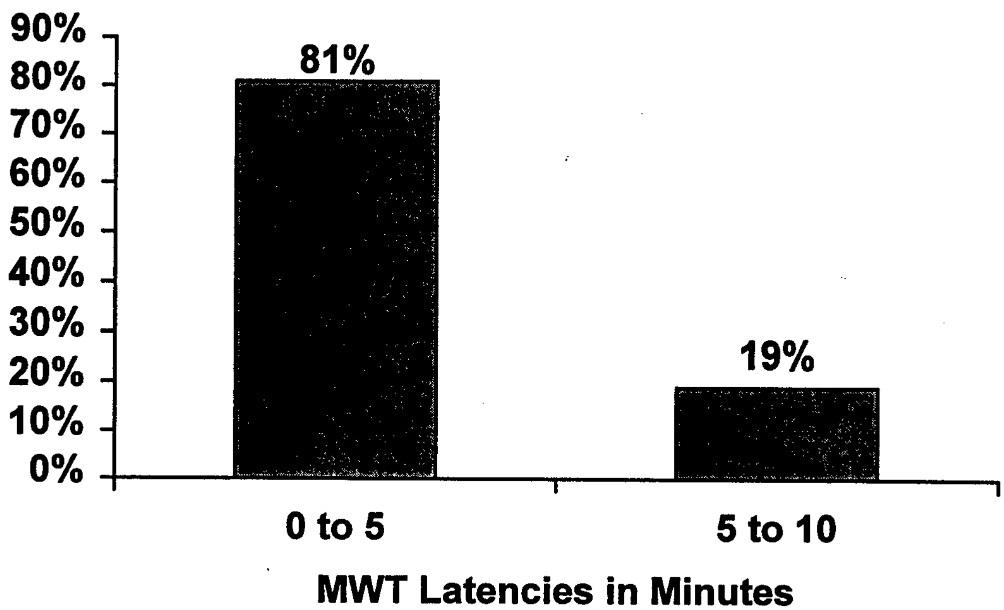

Figure 2. Percentage of MWT latencies above and below the clinical pathological threshold (five minutes) (n = 67).

For each participant, the percentage of MWT latencies at or below 8.2 minutes was calculated to further qualify the level of alertness degradation experienced throughout the patrol. The 8.2-minute threshold indicated degradation of alertness to levels indicating shiftwork maladaptation as reported by Campbell and Dawson in their 1997 report. Figure 3 depicts the percent of MWT latencies below 8.2 minutes for each of the 14 participants aboard the DEPENDABLE. For each participant, a wakefulness reduction index (WRI) score was calculated by determining the percent of tests with MWT scores below 8.2 minutes. Please refer to Table A-1 (Appendix A) for specific information on the raw data values, percentages, and number of observations associated with each value plotted in Figure 3. Throughout the 32-day test period, participants were tested from six to seven times.

Only one participant (case 25 in Figure 3) was able to remain awake in all test trials. Participant 32 exhibited minimal alertness degradation (failure rate of 29 percent), while cases 22 and 51 showed moderately high levels of alertness degradation with failure rates of 50 percent and 57 percent, respectively. In contrast, the remaining ten participants exhibited consistent evidence of alertness degradation with failure rates between 67-100 percent of the trials. Note that participants 23, 39, 44, and 50 were unable to maintain wakefulness for more than 8.2 minutes in 100 percent of the alertness trials.

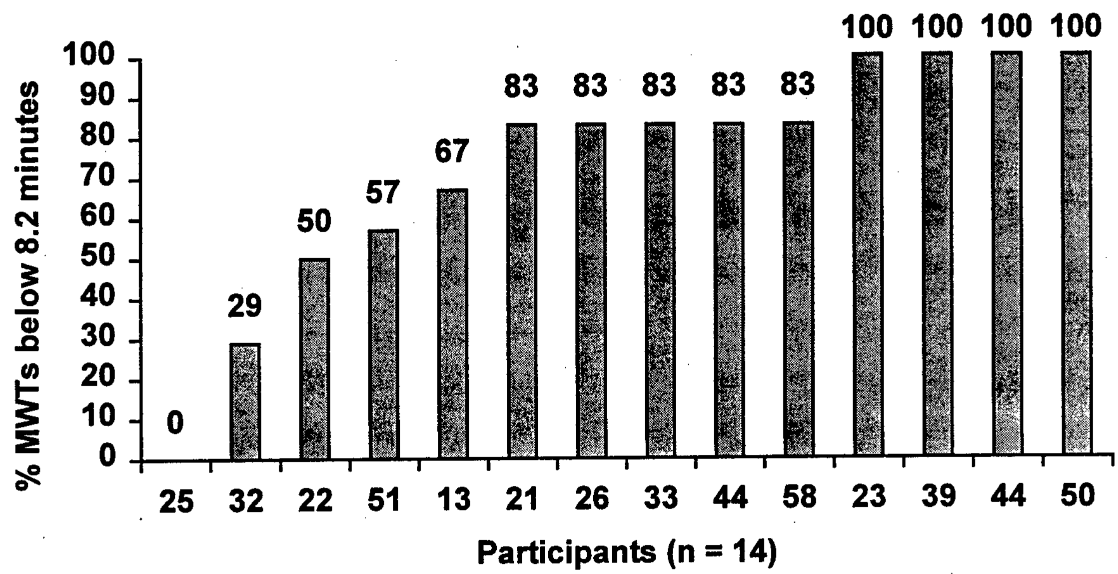

Figure 3. Wakefulness reduction index (percent of tests below 8.2 minutes) plotted for each volunteer participating in the MWT. Percent values denote failure rates throughout the 32-day patrol.

Crew Endurance Evaluation

Sleep/wake cycle evaluation

Sleep/wake cycle data (activity data from the WAMs) provide a daily history of activity and rest. Figures 4-7 depict individual profiles for four participants exposed to different watch schedules. In these illustrations, vertical lines indicate activity levels characteristic of wakefulness, while horizontal lines drawn above low activity periods indicate sleep (Figure 4). Clock times are shown at the bottom of the illustration.

Analysis of circadian sleep/wake profiles provided quantifiable evidence of the degree of stability or disruption of daily sleep. The frequency of changes in wake-up times and bedtimes throughout each circadian sleep/wake profile provided evidence of stability or disruption. Daily shifts in sleep and wake-up times, and in the subsequent timing of daily daylight exposure, disrupt the regulation of the body's biological rhythms and result in degradation of performance and alertness. Frequent daily reductions of less than six hours of consolidated sleep are also associated with degradation of alertness and performance of physical and mental tasks (Maas, 1998).

Underway sleep/wake profiles

Sleep/wake cycle histories were examined for volunteers with at least five consecutive work days (Figures 4-7). Each of these figures (Figures 4-7) represents a segment of that volunteer's sleep/cycle history throughout the study. In each segment, the magnitude and frequency of changes in sleep and wake-up times, the duration of the sleep period, and the incidence of increased activity during sleep were quantified using a seven-point scale. The scale values, herewith referred to as the Circadian Disruption Index (CDI) values, were used to indicate the degree of disruption or stability of each segment of five or more consecutive 24-hour days. Once a CDI value changes, a new segment begins.

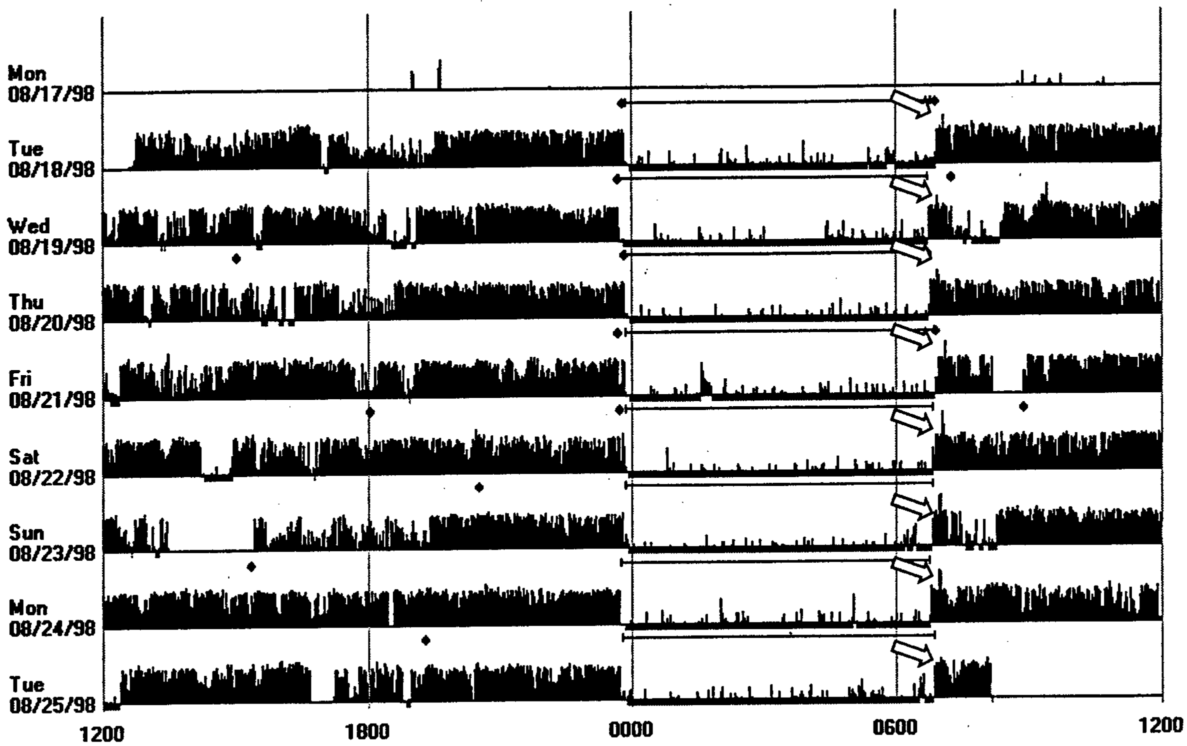

Figure 4. Activity data (obtained from activity monitors) plotted as a function of time of day to create a record of high and low activity throughout 24-hour days. Each row of data shows sleep, as indicated by horizontal lines above and below low activity periods, and wakefulness, as indicated by the black vertical lines. Arrows indicate wake-up time. This segment shows a very stable sleep/wake profile from day to day. Daily sleep of about seven consolidated hours takes place at the same time. (CDI = 1).

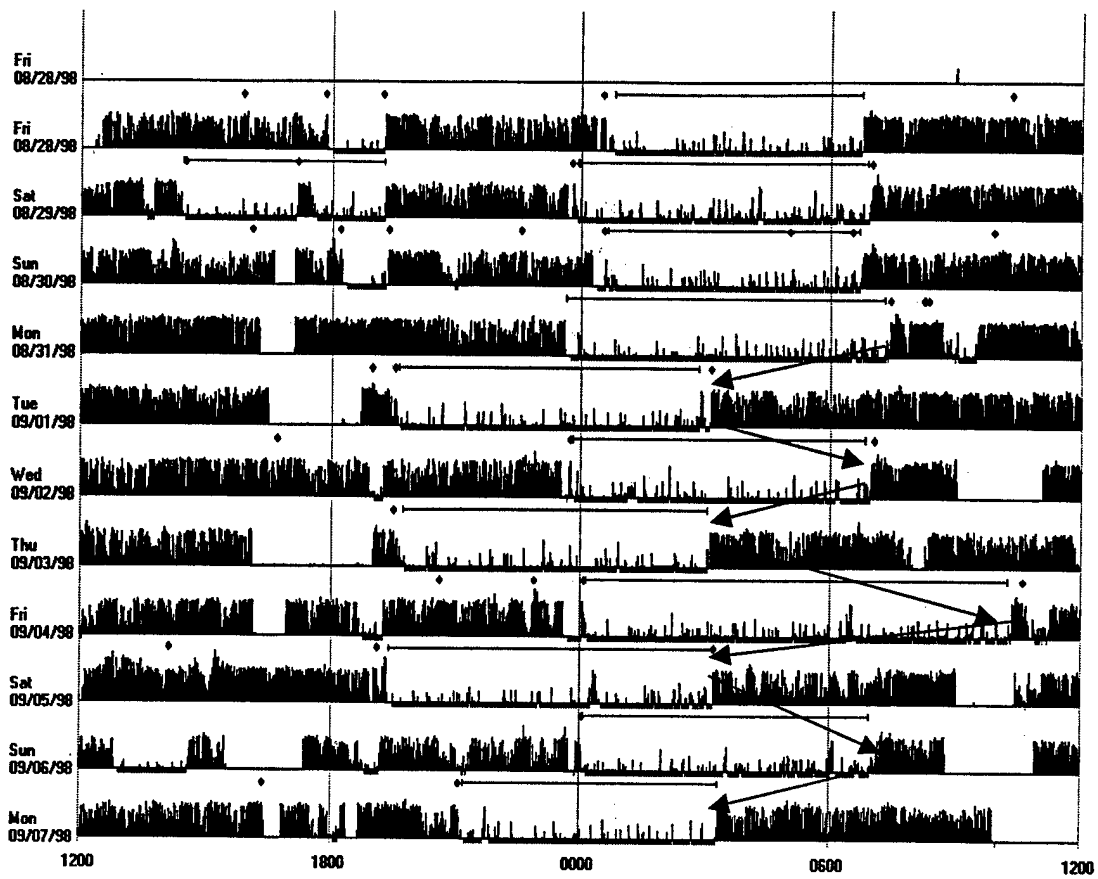

Figure 5. The induction of shift-lag via the use of watch schedules that prescribe the 0400-0800 schedule every other day. Note the frequent activity intrusions during the sleep period. Arrows (⟶) track the frequent shifts in wake-up times induced by changing watch schedules from day to day. (CDI = 6).

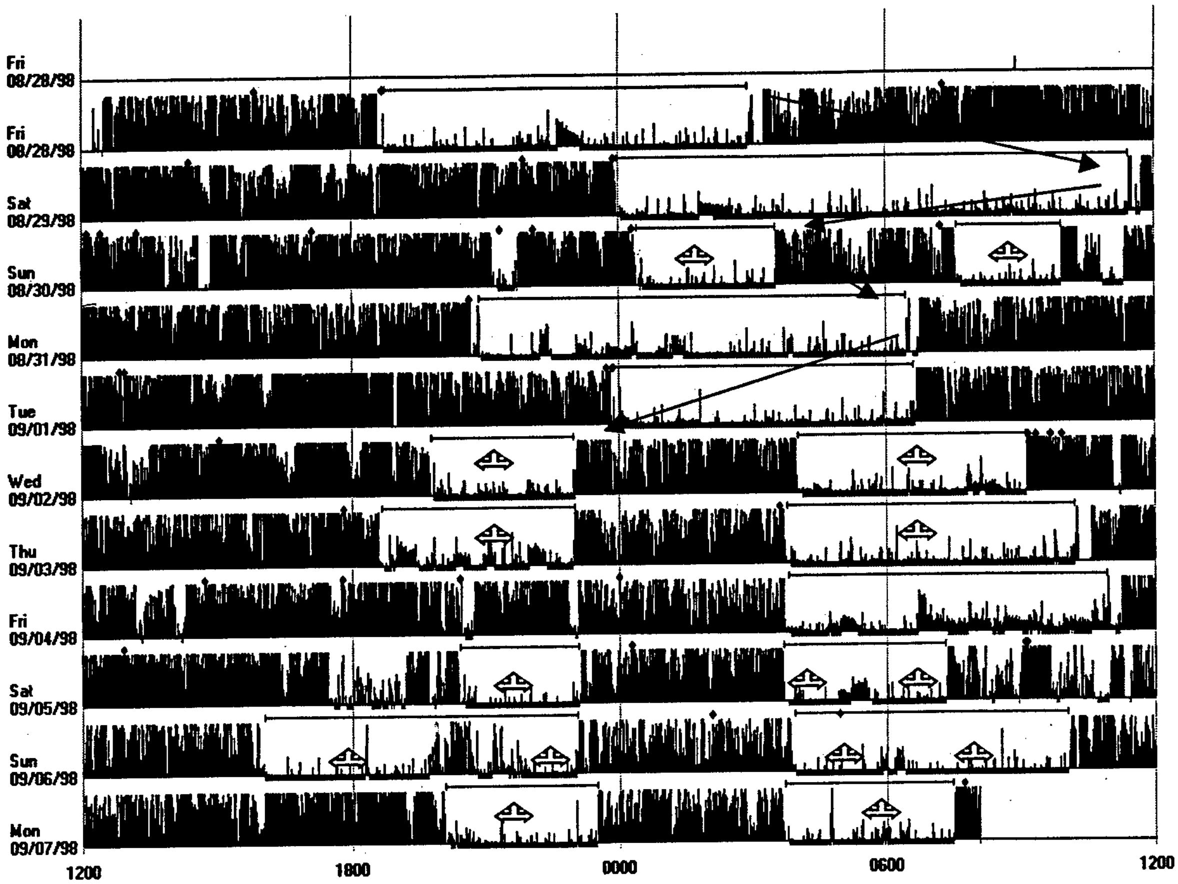

Figure 6. The induction of shift-lag by alternating the 0400-0800 (8/28-8/30) followed by a shift to 0000-0400 (9/02-9/07) within a six-day period. The black arrow symbol indicates shifts in bedtimes and wake-up times. The split arrow indicates sleep/wake cycle fragmentation and split sleep. (CDI = 7).

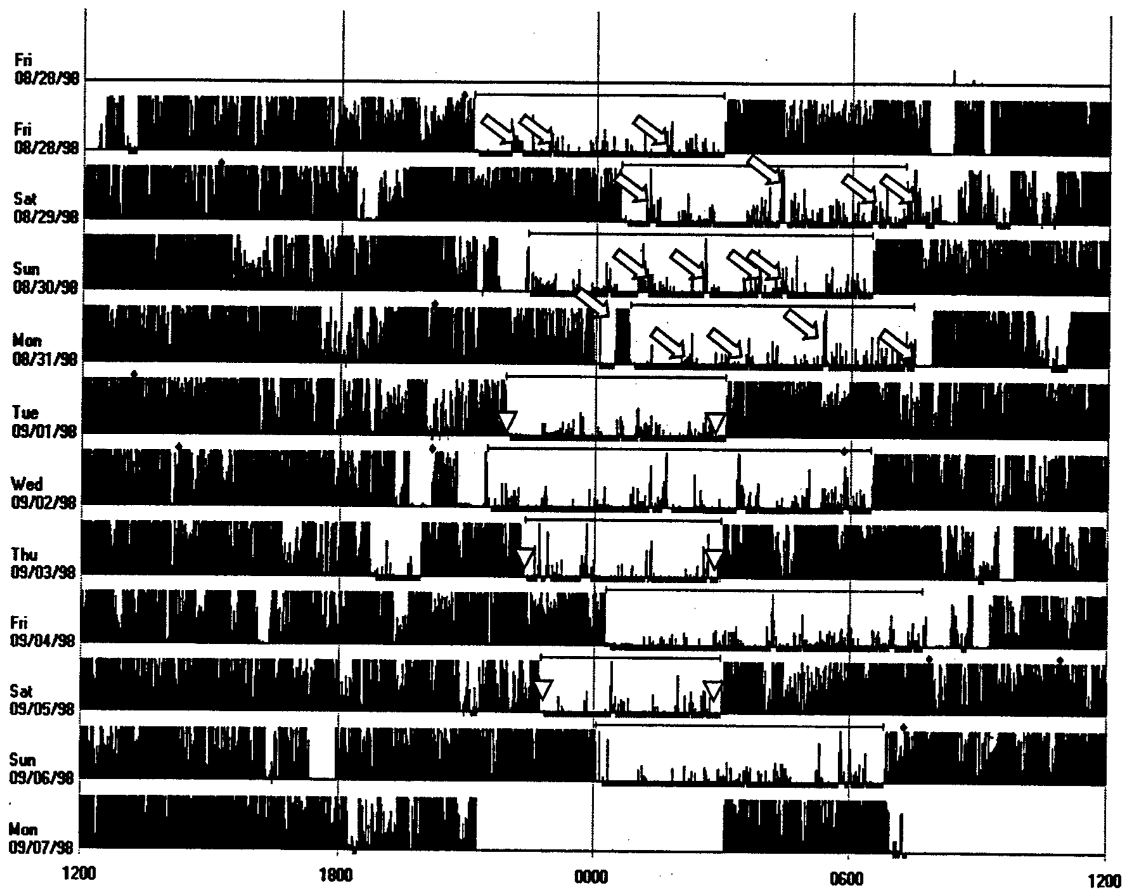

Figure 7. The induction of shift-lag by alternating the 0400-0800 and 0800-1200 watch schedules (9/1/98-9/7/98) within a seven day period. Arrows (⇘) indicate examples of awakenings during sleep. Downward arrows mark sleep periods of less than 6 hours (∇ ∇). (CDI = 6).

Figure 4 shows a very stable sleep/wake cycle profile from day to day. Daily sleep of approximately seven consolidated hours takes place at that same time. The highest disruption value (seven) was used to indicate evidence of persistent irregular bedtimes and wake-up times and of splitting of the sleep period (fragmentation). The term "fragmented sleep/wake cycles" is used to indicate that daily sleep was broken up into at least two periods (e.g., one period of three hours during nighttime and one period of four hours during daytime). Figure 6 depicts a sleep/wake cycle segment corresponding to a CDI value of seven. Note the occurrence of sleep/wake cycle fragmentation and daily advances and delays of bedtimes and wake-up times (arrows). Daily sleep must take place in consolidated and uninterrupted periods of at least six hours (in quiet and dark environments) to prevent performance degradation during waking hours (Maas, 1997, OTA report, 1991). CDI values of six and five were used to indicate a high incidence of daily changes in sleep and wake-up times occurring in the absence of sleep/wake cycle fragmentation. Figure 7 depicts a sleep/wake cycle segment corresponding to a CDI value of six. CDI values of five, six, and seven characterize a physiological condition in which the body's internal regulation of energy becomes disrupted (shiftwork maladaptation). This condition is characterized by fatigue symptoms similar to those experienced by international travelers (jet-lag) crossing more than five time zones.

Low CDI values (one, two, and three) were used to characterize the transition from stable sleep/wake cycles (one) to increasing sleep loss and frequent awakenings (two to three). These CDI values were not associated with daily changes in sleep and wake-up times. The mid-range CDI value of four was used to label sleep/wake profiles exhibiting increasing, but infrequent, variations in sleep and wake-up times. Table 1 provides a detailed description of the quantifiable characteristics associated with each CDI value.

Table 1. Description of quantifiable characteristics associated with CDI values used to analyze circadian activity profiles.

CDI	*Characteristics of Circadian Sleep/Wake Cycles*
1	• Consistent sleep and wake-up times from day to day (e.g., changes no greater than one hour), and • Sleep duration of more than six consecutive hours per day, and • No sleep disruption (e.g., frequent awakenings), and • No sleep/wake cycle fragmentation
2	• Sleep duration of six hours or less in no more than one out of five days, and • Sleep disruption (e.g., frequent awakenings), and • No sleep/wake cycle fragmentation, and • No changes in sleep and wake-up times greater than one hour per day
3	• Sleep duration of six hours or less observed more than once every five days, and • No sleep/wake cycle fragmentation, and • No changes in sleep and wake-up times greater than one hour per day
4	• Changes in sleep and wake-up times of one hour or greater observed no more than once every five days, and • No more than one 24-hour period showing sleep/wake cycle fragmentation associated with daily changes of wake-up times
5	• Variation in bedtimes and wake-up times of one hour or greater observed more than once every five days, and • No more than one 24-hour period showing sleep/wake cycle fragmentation associated with daily changes of wake-up times
6	• Frequent variations in bedtimes and wake-up times greater than one hour (e.g., every two days or more observed in at least five-day periods), and • No more than one 24-hour period showing sleep/wake cycle fragmentation associated with daily changes of wake-up times
7	• Frequent variations in bedtimes and wake-up times greater than one hour (e.g., every two days or more observed in at least five-day periods), and • Sleep duration below six hours observed more than once every five days, or • Fragmentation of sleep/wake cycles in two or more bouts throughout the 24-hour period associated with daily changes of wake-up times

Using the CDI, we analyzed 70 sleep/wake cycle records, consisting of five consecutive days or more, obtained from 25 volunteers throughout the 32 days underway. We found a 59 percent incidence of sleep/wake cycle disruption (CDIs five to seven). In most cases the disruption of the sleep/wake cycle was associated with frequent changes of watch schedules from daytime to 0000-0400 and/or to 0400-0800. The frequent rotation of personnel from daytime watches to nighttime and early morning reporting times induced frequent variations in bedtime, rise-times, and duration of sleep.

Figure 4 shows bedtimes, wake-up times, and sleep duration of a crew member who did not experience a significant disruption of the sleep/wake cycle during the period shown. In this particular case, the sleep/wake is scored with a CDI of one.

In contrast to Figure 4, the patterns in Figures 5 through 7 illustrate more commonly found sleep/wake cycle patterns experienced by DEPENDABLE's crew members. Figure 5 shows the disruption of a stable sleep/wake cycle pattern induced by incorporating the 0400-0800 watch every other day. Note the transition from a stable sleep/wake cycle pattern with a consistent watch schedule ending at approximately 0000 every other day (from 8/28-8/30) to a more unstable pattern of wake-up times varying from day to day (8/31 and beyond). Frequent bouts of activity are observed during the sleep period, indicating that this participant is tossing and turning frequently which prevents the establishment of deep sleep and dreaming. Although this crew member remained in bed for at least six consecutive hours per day, his or her sleep quality is diminished, resulting in a reduction in the restoration of physical energy and alertness resources. The sleep/wake cycle segment beginning on 8/31 is classified as a CDI of six because of the frequent shifts in wake-up time from day to day. This pattern of sleep can induce disruption of the biological clock's regulation of sleep, hormone production, neurotransmitter synthesis, cognitive resources and the restoration of alertness after sleep. It almost certainly results in fatigue and performance degradation. Recovery from this condition takes approximately four to seven days of consistent sleep and wake-up times.

Another example of activity patterns that result in disrupted sleep and biological clock instability is shown on Figure 6. This activity pattern contains disrupted and fragmented sleep/wake cycles again induced by changing work schedules. Note that a rapid transition from the 0400-0800 to the 2000-0000 watch occurs in a single 24-hour period (8/28-8/29). This transition is followed by duty on the 2000-0000 watch and, later that night, duty on the 0400-0800 watch. These rapid transitions from the 0400-0800 to the 2000-0000 induce inconsistent inputs to the biological clock as wake-up time is delayed and advanced from day to day. Long black arrows extending from one day to another are used to indicate the impact of shiftwork transitions on wake-up times. These arrows indicate delays and advances of wake-up time.

These rapid shiftwork transitions result in: a) the accumulation of sleep loss from day to day as consolidated sleep plummets below six hours; and b) the desynchronization of the biological clock due to changes in wake-up time and daylight exposure timing of more than two hours from day to day.

Later in the record (9/3), the watch schedule is stabilized to consecutive days of duty on the 0000-0400 watch. However, this participant responded by splitting the sleep period into two segments. Although these sleep segments help to maintain alertness for a few hours after wakefulness, particularly if their duration exceeds one hour (Maas, 1998), their restorative value is diminished. Note in Figure 6 that, in general, sleep segments lack restorative value due to frequent disruptions (see activity spikes during sleep) and lack of consolidated sleep (indicates split sleep). The biological clock does not initiate these periods of sleep. Their onset takes place due to increasing fatigue and sleepiness.

The brain needs to sleep in consolidated periods of at least six hours or more to optimize its restorative value (Maas, 1998). The adaptation of the biological clock to the constant 0400-0800 watch schedule can take place with the implementation of a daylight exposure schedule established from the first day on the 0400-0800 schedule (Comperatore, 1996). However, this crew member's sleep/wake history indicates that the biological clock's synchronization had been disrupted by rapid shiftwork transitions imposed from 8/28-8/30. Although, recovery sleep does take place on 8/31, this is not enough to compensate for the sleep loss experienced previously and for the desynchronization of biological timing. Thus, in this case, the biological clock's readjustment is hindered by previous insults to the system's stability. This crew member exhibited 100 percent of MWT latencies below five minutes (within the pathological range).

Figure 7 illustrates yet a different pattern of consistent variation in watch schedules resulting in disrupted sleep. The reduction of the sleep period can be seen throughout this record (see examples indicated by downward arrows ∇ ∇). Note that the 0400-0800 watch alternates with late night duty periods. In this case, sleep loss occurs frequently and it is associated with 0330-0400 reporting times. Again, as shown in previous cases, sleep periods lack restorative

value as indicated by activity spikes throughout the sleep period (arrows ↘ illustrate awakenings during sleep). This sleep/wake cycle pattern is representative of records classified as a CDI of six.

<u>Relationship between disrupted sleep/wake cycles and alertness reduction</u>

Further analyses were conducted to determine whether a sleep/wake cycle disruption, as classified by CDI values, was associated with the reduction of alertness as indicated by MWT latencies. For this purpose, MWT latencies were grouped under two categories, those recorded in association with CDIs between one and three, and those recorded in association with CDIs between five and seven. A one-way Analysis of Variance (ANOVA), applied to these two groups of observations, revealed that MWT latencies were significantly lower ($p < 0.05$) when recorded in association with CDIs between five and seven (mean = 4.72 minutes) than with CDIs between one and three (mean = 9.42 minutes). Figure 8 depicts the differences between latencies grouped under the two CDI categories.

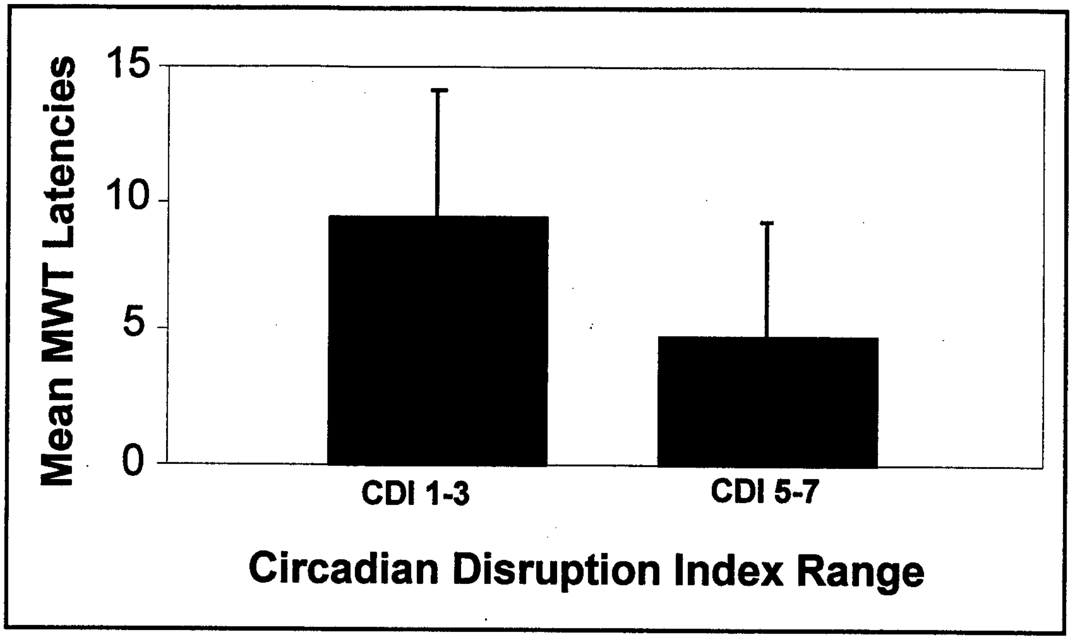

Figure 8. Mean MWT latencies grouped under low (CDI 1-3, n = 191) and high (CDI 5-7, n = 404) circadian disruption categories. Error bars indicate sample standard deviations. Significant differences between the two groups were confirmed via a one-way ANOVA, $F(1, 78) = 15.56$, $p < 0.05$ and the Tukey-Honest Significance Difference Test for unequal sample sizes ($p < 0.05$).

Note that the mean MWT latencies obtained from tests associated with sleep/wake cycle patterns exhibiting consistently high circadian disruption (CDIs between five and seven) are below the clinical pathological threshold of five minutes. Appendix B contains a more detailed account of the tests and results that establish the statistical significance of these differences.

Relationship between disrupted sleep/wake cycles and daily sleep loss

The human brain needs daily periods of consolidated sleep of at least six hours or more to restore cognitive and physiological resources (Maas, 1998). In our study sample, we found a circadian disruption incidence (CDIs five to seven) of 59 percent, thus indicating frequent disruption of daily sleep/wake cycles (bedtime and wake-up time). Systematic disruption of sleep/wake cycles can be expected to result in sleep disturbances that may reduce sleep duration below six hours

per day. Consequently, further analyses were conducted to determine whether sleep/wake cycle disruption was associated with the reduction of sleep duration. For this purpose, daily sleep duration scores (in minutes) were grouped under two categories, those recorded in association with stable sleep/wake cycles (CDIs between one and three) and those recorded in association with high levels of circadian disruption (CDIs of five to seven) (Figure 9). A Kruskil-Wallis ANOVA (Siegel, 1956) applied to the two groups of observations, revealed that sleep duration was significantly lower ($p < 0.05$) when recorded in association with CDIs between five and seven (mean = 348.98 minutes or 5.8 hours) than in association with CDIs between one and three (mean = 426.68 minutes or 7.1 hours). Note that average sleep duration under CDI values from five to seven was below six hours (360 minutes). The confirmation that sleep falls below six hours under CDI from five to seven indicates that the sleep/wake cycle disruption experienced on DEPENDABLE has the potential to deteriorate performance by depriving the brain of needed sleep time. Please refer to Appendix B for a more detailed description of the statistical approach and rationale used in this section.

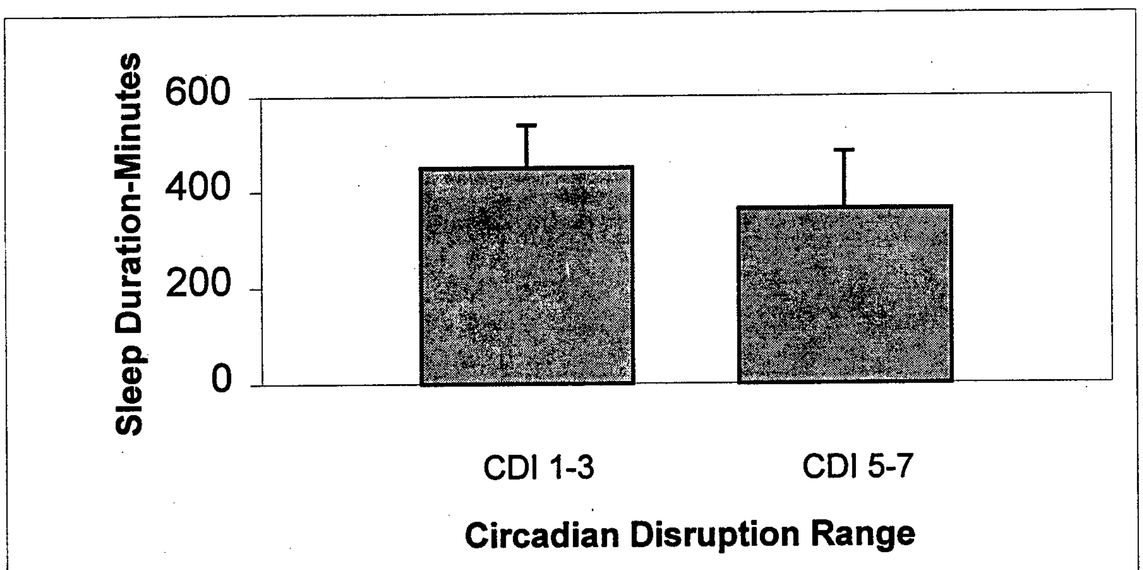

Figure 9. Mean sleep duration recorded from activity data grouped under low (CDI 1-3, n = 191) and high (CDI 5-7, n = 404) circadian disruption categories. Error bars indicate sample standard deviations.

Breakdown of the Circadian Disruption Index (CDI) as a function of department membership

Figure 10 provides frequency plots of the disruption of sleep/wake cycles for each department/grouping. Participants were grouped as a function of similar duty assignments. Note that sleep/wake cycles of the engineering group were found in high concentration above a CDI of four. This indicates that disruption of sleep timing was frequently observed in the sleep/wake profiles of crew members in the engineering group. CDI values of five and above indicate the frequent incidence of changes from daytime to nighttime duty hours on a weekly basis.

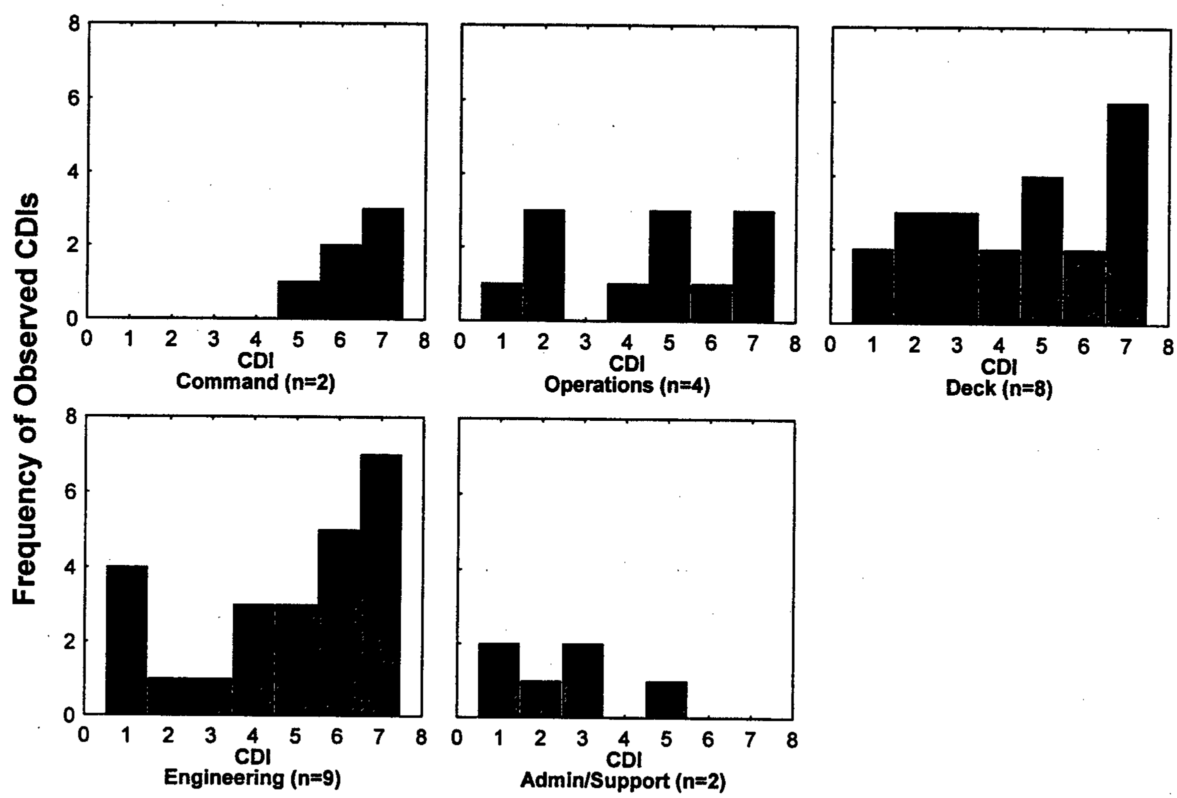

Figure 10. Number of observations plotted over CDI values (1-7) for each department. Each frequency count indicates the number of sleep/wake cycle profiles classified under the CDI category (horizontal axes). CDI values 1-3 indicate low to moderate disruption and values from 4-7 indicate increasing levels of sleep/wake cycle disruption. Numbers 0 and 8 are plotted only as reference points.

Observations concerning patrol

In general, the patrol was characterized as a low tempo patrol with unremarkable sea conditions. There were few boardings and flight operations compared to anticipated activities following discussions with DEPENDABLE's wardroom officers. On 25 of the 32 patrol days during which a data collection team was on-board, seas were characterized as calm to wave heights of three feet, or the DEPENDABLE was in port. On the other seven days, wave heights ranged up to eight feet.

After nine days at sea, there was a two-day port call in Boston. Following an additional 11 days at sea, there was a two-day port call in Portland. The data collection portion of the patrol terminated in Halifax after an additional eight days at sea. Throughout the study, crew members complained of noise levels (piped announcements) and confined sleeping space in berthing areas. Unfortunately, instead of catching up on needed sleep during port calls, many crew members tended to engage in recreational activities. The result was that they would leave a port call possibly more tired than when they arrived.

CONCLUSIONS AND RECOMMENDATIONS

The observation that 12 out of 14 participants failed to maintain wakefulness above 8.2 minutes in 50 percent to 100 percent of all wakefulness tests strongly suggests that these participants experienced a persistent loss of alertness throughout the 32 days of the study (Figure 3). The documentation of sleep/wake cycle disruptions (Figures 4-7) and their association with frequent failure to maintain wakefulness (Figure 8) supports the notion that watch schedules significantly contribute to the degradation of alertness. Frequent rotations from daytime duty to the 0000-0400 or 0400-0800 watch schedules induce lack of stability of the sleep/wake cycle and disruption of the internal timing of the biological clock.

Experimental and clinical evidence indicates that rapid shifts in work schedules have a detrimental impact on health and physiological well being (Kogi, 1985; Scott & Landou, 1990; Smolensky & Reinberg, 1990; Office of Technological Assessment [OTA], 1991). In general, varying reporting times from day to day is often associated with the disruption of the sleep/wake cycle, sleepiness, reduced alertness, deterioration of performance, and physical discomfort associated with gastrointestinal disorders (Comperatore & Krueger, 1990; Monk, 1990; OTA, 1991). In this study, the frequent observation of variable rise times, as indicated by circadian disruption index data, implies that the biological clock may have received inputs causing frequent timing readjustments from day to day. Similarly, changes in alertness are experienced by much of the general public during the transition to daylight savings time (Maas 1998). Usually this change is only a one hour advance in rise time and daylight exposure time, yet it is well documented that the U.S. population at large experiences sleepiness during the first week of the change. In the case of DEPENDABLE's crew exposed to the 0000-0400 or 0400-0800 watch schedules, their changes in rise times varied by more than one hour and often occurred several times within a month or sometimes within a week.

It should be noted that sleepiness and alertness degradation can also be caused by motion discomfort. Since the experience of motion discomfort varies from participant to participant on a day to day basis, its contribution to degraded alertness during duty hours is very difficult to control. Because weather conditions were largely unremarkable during the study period (seas usually under three feet), we believe that motion discomfort made little or no contribution to the inability of the crew to maintain wakefulness in our tests. We conclude that the primary cause of crew fatigue and sleepiness was the changing watch schedules.

Watch schedules used aboard DEPENDABLE prescribed frequent rotations from daytime duty to nighttime duty within seven and 14-day periods. Weekly rotations into the 0000-0400 and 0400-0800 watch schedules contributed to the disruption of the sleep/wake cycle. While the effects of motion discomfort are difficult to control without pharmacological interventions, we can effectively minimize fatigue associated with watch schedules via the implementation of more stable schedules.

One characteristic of watch schedules that adversely affects sleep duration and the stability of the sleep/wake cycle is the frequency of rotation from daytime to nighttime duty hours. The best approach is to minimize the frequency of rotation from daytime to nighttime duty hours. For instance, reducing the frequency of the rotation from daytime to nighttime watch schedules to a two-week interval will allow crew members to adapt more readily. The adaptation takes place as the biological clock resynchronizes physiological, biochemical, and cognitive functions with the new sleep/wake cycle. Thus, stabilizing a crew member's watch schedule to three consecutive weeks in the 0400-0800 watch will be much less disruptive than alternating the 0400-0800 with the 0800-1200 watch schedule every other day. Although the alternating schedule may seem to relieve the crew member from getting up early every morning, it actually results in inconsistent inputs to the biological clock. As shown throughout the activity/rest cycle examples (Figures 5-7), if wake up time varies from 0330 to 0630 or later every other day, the biological clock receives variable inputs as to when the energy cycle should begin.

Since the biological clock takes approximately 72 hours to re-adjust rhythms to a new sleep/wake cycle and the accompanying changes in exposure to daylight, it cannot respond fast enough in rapidly rotating watch schedules as in the examples in Figures 5-7. Reducing the frequency of the watch schedule rotation (e.g., three weeks rotation) allows the biological clock to adapt to the new work schedule in the first three days and to maintain a steady state of synchronization for the remainder of the three weeks. Light exposure management schedules must be observed to optimize the readjustment of biological timing. During this period, the individual reaps the benefits of a stable sleep schedule and the potential to maximize the benefits of each rest period.

Thus, watch schedule rotation frequencies of two weeks or more will stabilize sleep/wake cycles and improve sleep quality. Under slowly rotating watch schedules, CDI values will remain within one to three and alertness degradation can be expected to be minimal under good weather conditions. Wakefulness tests can be expected to yield failure rates below 50 percent. However, sea states and possible motion discomfort, and individual physiological differences, will remain significant contributors to the physiological cost of doing business at sea.

In general, personnel reductions, a low ratio of qualified to unqualified watch personnel, and higher operational tempo will synergistically influence the need to increase the frequency of watch rotations. Traditionally, personnel are scheduled to rotate evenly throughout each watch. This ensures that no one is consistently exposed to an undesirable watch schedule. Rotation frequency increases with reduced numbers of qualified personnel. The results reported here are not unique to DEPENDABLE. A fatigue evaluation aboard the 378-ft cutter MUNRO revealed that nine out of 14 MWT volunteers exhibited consistent disruptions of sleep/wake cycles in association with alertness degradation (Comperatore, Bloch, and Ferry, 1999). As was the case on DEPENDABLE, MUNRO's volunteers also exhibited greater than 50 percent incidence of circadian disruption in their sleep/wake profiles. In both fatigue evaluations, the operational tempo was not particularly high, weather conditions were unremarkable, and sea states were moderate. Thus, it is possible to conclude that in both cutters, the architecture of watch rotations and not the specific crew reductions consistently contributed to the disruption of sleep/wake cycles and alertness degradation.

Under the current crew training system, Paragon crew reductions may contribute to keeping low numbers of watch qualified personnel. This condition will promote the use of "port and starboard" (e.g., 0400–0800 and 1600–2000) watch rotations, thus increasing work hours and fatigue levels.

In shiftwork environments, prevention of alertness degradation and circadian disruption can be accomplished by the implementation of crew endurance plans (Comperatore et al., 1996, see Appendix C). These plans consist of the implementation of work schedules designed to minimize circadian disruption and of education programs that provide information on how to optimize crew rest and minimize desynchronization of the biological clock (e.g., use of light disciplines to minimize shift-lag).

Crew endurance education programs should be developed for implementation by Coast Guard Headquarters, and transmitted throughout the CG cutter community. These programs can help crew members realize the critical importance of rest opportunities and develop adaptive behaviors

to prevent fatigue and optimize alertness and endurance. A critical requirement for the success of any crew endurance plan is explicit support from CG management. Without the support and participation of the entire CG cutters' complement, no lasting changes can be implemented in the CG cutter community.

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APPENDIX A

MWT Latency Table

Table A-1. MWT Latency Table

Participant	Date Of MWT	MWT Latency (min.)	No. MWT	MWT %<5min	MWT %<8.2min (WRI)	MWT %<10min	Average MWT Latency	MWT Latency Std. Dev.	Average CDI
13	21-Aug	12.08	6	67%	67%	83%	5.50	4.26	4.00
	25-Aug	9.68							
	1-Sep	2.33							
	4-Sep	2.75							
	11-Sep	3.58							
	15-Sep	2.58							
21	19-Aug	3.45	6	50%	83%	83%	5.72	5.43	4.00
	22-Aug	7.31							
	2-Sep	0.33							
	5-Sep	7.25							
	15-Sep	15.00							
	16-Sep	1.00							
22	20-Aug	15.00	6	50%	50%	50%	9.03	6.72	6.00
	24-Aug	0.21							
	31-Aug	15.00							
	4-Sep	4.41							
	7-Sep	15.00							
	14-Sep	4.56							
23	23-Aug	3.06	6	83%	100%	100%	4.23	1.92	6.00
	24-Aug	8.08							
	31-Aug	3.50							
	6-Sep	3.91							
	12-Sep	3.75							
	14-Sep	3.08							
25	20-Aug	15.00	6	0%	0%	0%	15.00	0.00	2.60
	24-Aug	15.00							
	31-Aug	15.00							
	3-Sep	15.00							
	7-Sep	15.00							
	16-Sep	15.00							
26	21-Aug	4.75	6	83%	83%	83%	3.97	3.42	6.67
	25-Aug	3.25							
	1-Sep	3.35							
	4-Sep	10.31							
	11-Sep	1.25							
	15-Sep	0.91							
32	19-Aug	8.28	7	29%	29%	43%	10.51	5.99	1.30
	22-Aug	15.00							
	29-Aug	4.41							
	2-Sep	15.00							
	5-Sep	15.00							
	12-Sep	15.00							
	15-Sep	0.91							

Table A-1. MWT Latency Table (continued)

Participant	Date Of MWT	MWT Latency (min.)	No. MWT	MWT %<5min	MWT %<8.2min (WRI)	MWT %<10min	Average MWT Latency	MWT Latency Std. Dev.	Average CDI
33	20-Aug	7.30	6	67%	83%	83%	5.88	4.88	6.30
	24-Aug	3.91							
	31-Aug	4.46							
	3-Sep	3.33							
	11-Sep	1.25							
	14-Sep	15.00							
39	19-Aug	3.80	6	100%	100%	100%	1.48	1.43	5.67
	22-Aug	1.10							
	29-Aug	2.66							
	2-Sep	0.25							
	5-Sep	0.41							
	16-Sep	0.66							
44	19-Aug	6.33	6	67%	83%	100%	4.36	2.62	4.30
	22-Aug	4.00							
	31-Aug	2.16							
	4-Sep	8.50							
	12-Sep	1.58							
	15-Sep	3.61							
50	19-Aug	5.15	7	71%	100%	100%	3.78	1.32	7.00
	22-Aug	2.08							
	29-Aug	5.66							
	2-Sep	4.33							
	5-Sep	3.55							
	12-Sep	2.66							
	16-Sep	3.00							
51	19-Aug	5.28	7	29%	57%	57%	7.85	5.85	4.00
	22-Aug	6.25							
	1-Sep	10.75							
	4-Sep	15.00							
	5-Sep	15.00							
	12-Sep	1.85							
	16-Sep	0.83							
55	23-Aug	0.31	6	100%	100%	100%	0.81	0.55	5.40
	25-Aug	1.00							
	1-Sep	1.08							
	4-Sep	0.16							
	14-Sep	1.66							
	15-Sep	0.66							
58	20-Aug	3.11	6	83%	83%	100%	2.50	3.14	3.00
	24-Aug	8.58							
	31-Aug	1.00							
	3-Sep	0.50							
	7-Sep	1.50							
	16-Sep	0.33							

APPENDIX B

STATISTICAL ANALYSES

Rationale for the Statistical Analysis of MWT Data

Analyses were conducted to determine whether a relationship existed between sleep/wake cycle disruption and alertness level as indicated by MWT latencies and CDI values. For this purpose, MWT latencies were grouped under two categories, those recorded in association with CDIs between one and three and those recorded in association with CDIs between five through seven.

Test of homogeneity of variance. The results of the Levene Test of Homogeneity of Variances revealed no significant differences ($F(1,78) = 8.31$, $p = 0.08$) between the variances of the two groups (variance CDI one to three = 27.58 and variance CDI five to seven = 20.81). Therefore, the use a parametric ANOVA test was justified.

A One-Way Analysis of Variance (ANOVA), applied to these two groups of observations, revealed a significant main effect of the factor sleep/wake cycle disruption or CDI ($F(1,78) = 15.56$, $p < 0.01$). A Post-Hoc test, the Tukey Honest Significant Difference test, for unequal sample sizes, was applied to the latencies under the two CDI groups, namely, no disruption (CDIs one to three) and disruption (CDIs five to seven). This test confirmed that MWT latencies were significantly lower ($p = 0.001$) when recorded in association with CDIs between five to seven (mean = 4.72 minutes) than with CDIs between one and three (mean = 9.42 minutes). Figure B-1 depicts the differences between latencies grouped under the two CDI categories.

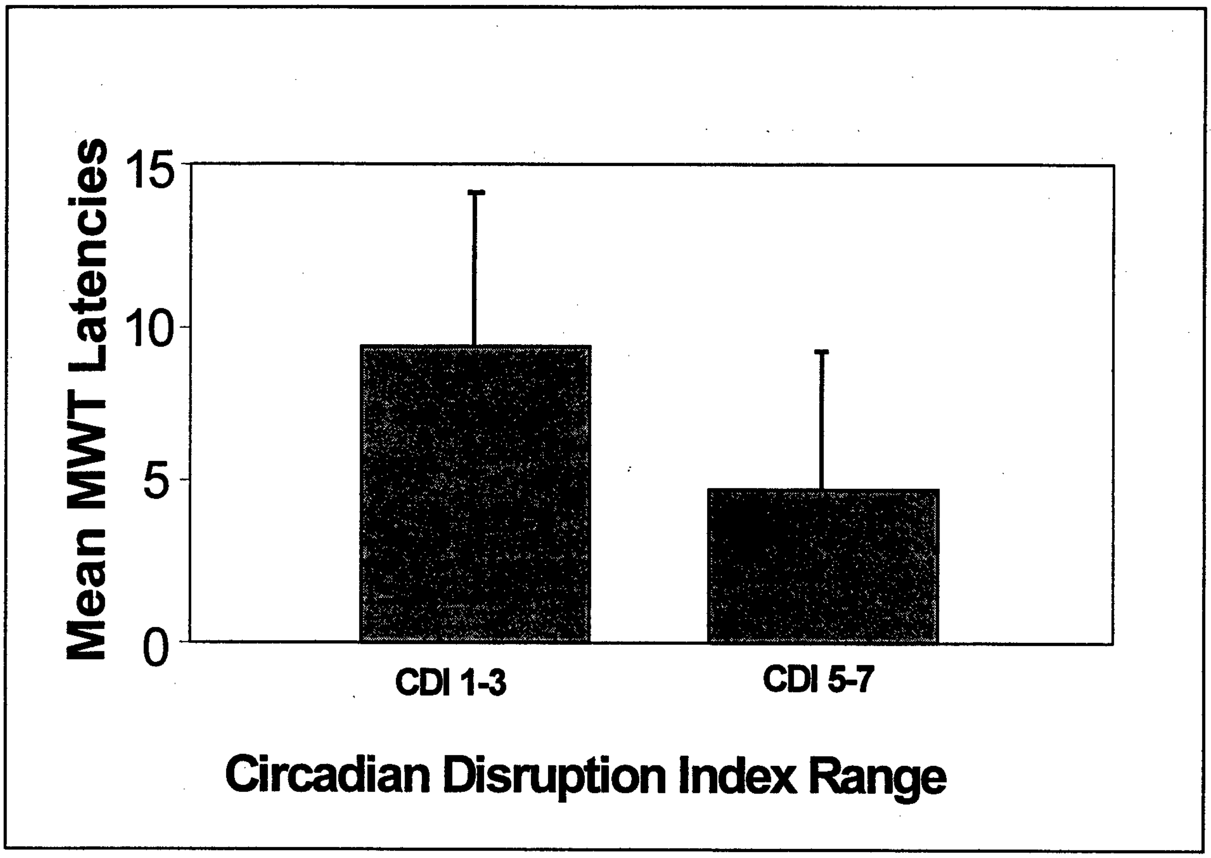

Figure B-1. Mean MWT latencies grouped under low (CDI 1-3, n = 25) and high (CDI 5-7, n = 55) circadian disruption. Error bars indicate sample standard deviations. Significant differences between the two groups were confirmed via a one-way ANOVA, $F(1,78) = 15.56$, $p < 0.01$ and the Tukey-Honest Significance Difference Test for unequal sample sizes ($p =0 .001$).

Rationale for the Statistical Analysis of Sleep Duration Data

In our study sample, we found a circadian disruption incidence of more than 50 percent, thus indicating frequent disruption of the stability (bedtime and wake-up time) of daily sleep/wake cycles. Systematic disruption of sleep/wake cycles can be expected to result in sleep disturbances that may reduce sleep duration below six hours per day. Consequently, further analyses were conducted to determine whether sleep/wake cycle disruption was associated with the reduction of sleep duration. Sleep duration was calculated by adding the number of consecutive hours of sleep obtained during the subjective night just prior to the beginning of a new work day. Daily sleep duration scores (in minutes) were grouped under two categories,

those recorded in association with stable sleep/wake cycles (CDIs between one and three) and those recorded in association with high levels of circadian disruption (CDIs of five to seven).

Tests of homogeneity of variances revealed significant differences of variance between observations recorded under stable sleep/wake cycles (CDIs one to three) and those recorded under severe circadian disruption (CDIs from five to seven). The results of the Levene Test of Homogeneity of Variances revealed a significant difference ($F(1,617) = 7.88$, $p < 0.01$) between the two groups.

In cases when the use of parametric statistics is not possible due to violation of assumptions such as homogeneity of variances, Siegel (1956) recommends the use of the nonparametric One-Way Analysis of Variance (ANOVA) equivalent, namely the Kruskil-Wallis ANOVA. The nonparametric ANOVA equivalent is a distribution free test that can be conducted in sets of observations with significant variance differences. Unlike the parametric ANOVA, when using the Kruskil-Wallis ANOVA, the null hypothesis can be rejected only with a large effect size.

The Kruskil-Wallis ANOVA (Siegel, 1956) applied to the 2 groups of observations, revealed that sleep duration was significantly lower ($H(1, n = 595) = 49.23$, $p < 0.05$) when recorded in association with CDIs between five and seven (mean = 348.98 minutes) than in association with CDIs between one and three (mean = 426.68 minutes). Note that average sleep duration under CDIs values from five to seven were below six hours (360 minutes). Figure B-2 depicts the differences between latencies grouped under the two CDI categories.

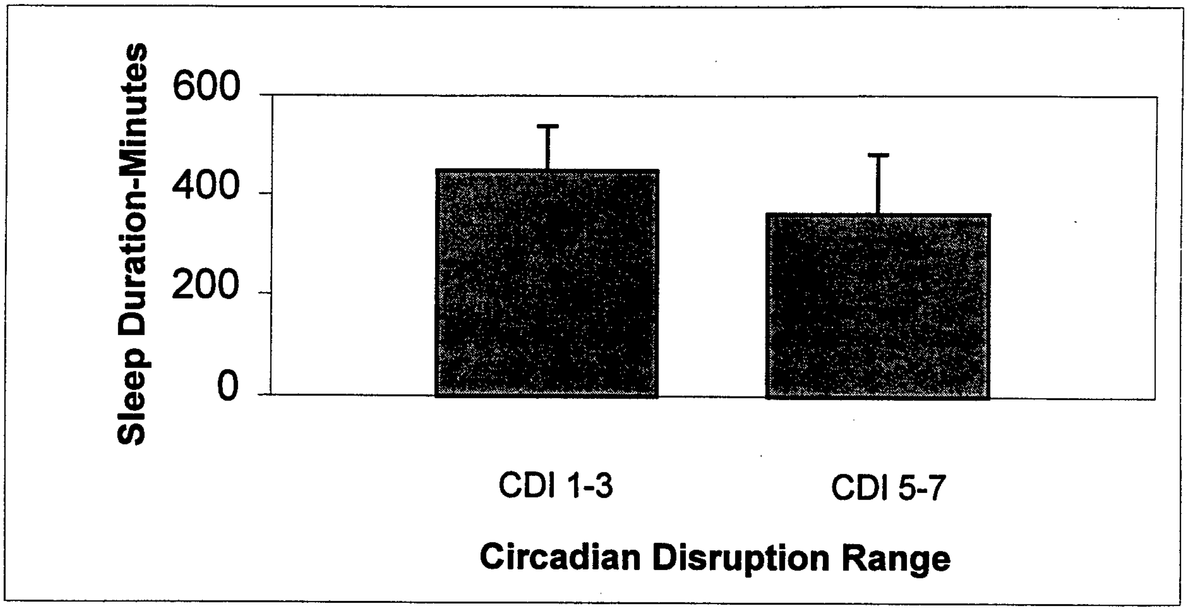

Figure B-2. Mean sleep duration recorded from activity data grouped under low (CDI 1-3, n = 191) and high (CDI 5-7, n = 404) circadian disruption categories. Error bars indicate sample standard deviations. Significant differences between the two groups were confirmed via a Kriskal-Wallis One-Way ANOVA test H (1, n = 595) = 49.23, p <0.05.

APPENDIX C

Crew Endurance Management System

Crew Endurance Management System (CEMS) (Comperatore, 1996), developed for Army Aviation in the 1990s, has been adapted for the specific requirements of U.S. Coast Guard aviation missions (Comperatore, Bloch, and Ferry, 1998). Following, we provide a detailed description of the Coast Guard version of the Crew Endurance Management System (CGEMS) adapted for WHECs (High Endurance Cutter) and WMECs (Medium Endurance Cutter). This system coordinates mission specific objectives, workload, human resources, work schedules, equipment constraints, administrative duties, and family and social activities to prevent sleep loss, high stress levels, and performance degradation during missions (Comperatore, 1996; Comperatore and Allan, 1997; Comperatore et al., 1998).

The CGEMS consists of mission specific plans designed to maximize alertness during duty hours by optimizing sleep efficiency during rest periods and reducing emotional stress. Figure C-1 illustrates the crew endurance system, consisting of four levels of coordination, namely, 1) mission objectives, 2) personal endurance, 3) watch, maintenance, and training schedules, and 4) collateral duties.

The Center of the Model

Mission objectives are at the center of the model and these are the reference for all other coordination. This first level element of the system consists of the type of mission (e.g., law enforcement, or search and rescue, etc.), geographical region, time of day of mission (e.g., daytime or nighttime), and weather conditions. The effectiveness of the CGEMS relies on its emphasis of adjusting the plan to the mission's objectives, and on the ability to maximize rest and alertness by implementing a practical and well-coordinated plan.

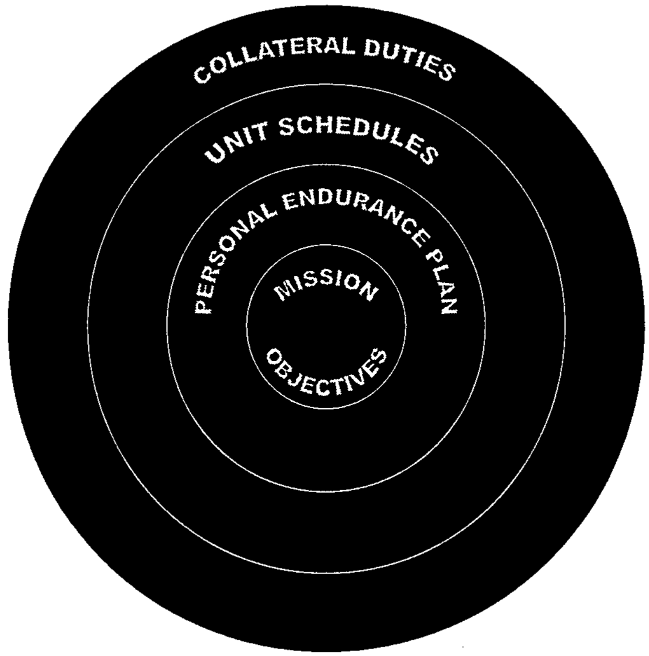

Figure C-1. CGEMS model depicting the four levels and the relative flexibility of each level. (Mission objectives (Level I) is the least flexible level, indicated here by a central position. Levels increase in flexibility away from the center.)

The Second Level: Personal Endurance

In the second level, the CGEMS recommends crewmember activities to maintain high levels of alertness during duty hours, maximize sleep efficiency, regulate the biological clock, and maximize the balance between family life and work demands. Table C-1 depicts some of these activities. The success of these individual efforts depends on their coordination with the first, third and fourth levels of the model.

Table C-1. Sample of CGEMS Prescribed Level I Activities

Level I Activities	Functional Significance
Design sleep management schedules to meet the demands of mission flights	Prevent fatigue induced by short duration sleep periods and optimize sleep by prescribing best times of the day to sleep
Implement recommendations to optimize the sleep environment	Control of noise and light intrusions, prevent fatigue induced by unnecessary fragmentation of the sleep period
Implement daylight exposure schedules	Prevent fatigue and performance degradation induced by the disruption of the body's internal timing system (shift-lag)
Inform family members in advance of deployment schedule and plan at least one family activity prior to departure	Reduce alienation of family members and use actions to demonstrate affection
Schedule meals and control composition of meals to minimize digestive disruptions	Minimize sleep disruption induced by disrupted digestive function

The Third Level: Unit Schedules

This level consists of schedule activities that directly impact the mission and crew readiness. These activities need to be planned and scheduled so that they simultaneously accomplish the mission, and also, promote crew alertness. Such activities include briefings, planning sessions, meal schedules, training schedules, and schedules of instruction periods on crew endurance management for all unit personnel.

The Fourth Level: Collateral Duties

The elements of this level constitute activities related to activities that pose additional workload to watch schedules and departmental work hours. These activities must be scheduled to prevent the disruption of sleep management during underway and in-port periods.

Implementation of the CGEMS

The process of implementing the CGEMS to develop a crew endurance plan requires an initial or Phase I evaluation of the impact of the unit's current operational policies on crew rest. This evaluation must be conducted during at least a 15-30-day period to properly document duty hours, workload, and crew rest associated with low and high tempo operations. Depending on the geographical location (e.g., Alaska vs Florida), operational tempo and workload may be directly affected by seasonal changes; thus, some evaluations must be conducted during both winter and summer seasons. This evaluation provides information on the elements that require coordination across the four levels of the system. The present manuscript describes the outcomes of a Phase I evaluation.

In addition to this analysis, the successful implementation of the CGEMS requires the activation of an aggressive education program designed to instruct wardroom officers, chiefs, and unit personnel on their contribution to the coordination and execution of the various elements. The next step requires the development of a Crew Endurance Quality Action Team (QAT). The composition of this team requires officers and senior chiefs from each department. The QAT then meets to develop a crew endurance plan from the information provided in the Phase I evaluation. The QAT submits the plan to the command staff (e.g., Commanding Officer (CO), Executive Officer (XO), and Operations) and, after approval, implements the plan during a typical patrol. The efficacy of the plan is determined using a similar test protocol to the one presented in this manuscript.

The second or Phase II crew endurance evaluation requires the use of activity monitors to objectively document the impact of watch, work, and training schedules on crew rest, and the

documentation of daily activities using electronic or paper personnel logbooks. These data are used to determine whether crewmembers' rest periods are consistent and sufficiently long to restore alertness and physical energy from day to day.

Further information on how to develop crew endurance plans, and to implement Phase I and Phase II evaluations can be obtained by contacting the Crew Endurance Team at the U.S. Coast Guard Research and Development Center in Groton, CT (860-441-2600) or U.S. Coast Guard Headquarters (G-WKS-3) at (202-267-2244).